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Scientific Article

Intermodality Variability in Gross Tumor Volume Delineation for Radiation Therapy Planning in Oropharyngeal Squamous Cell Carcinoma

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Purpose: Multimodality imaging can enhance the precision of tumor delineation for intensity modulated radiation therapy planning. This study aimed to analyze intermodality variation for gross tumor volume (GTV) delineation in locally advanced oropharyngeal carcinomas (LAOCs).

Methods and Materials: We examined the pretreatment contrast-enhanced computed tomography (CECT), magnetic resonance imaging (MRI), and fluoro-deoxy-glucose-based positron emission tomography (FDG-PET) image data sets of 33 adult patients with primary LAOC. Automatic segmentation method was used to derive PET-based metabolic tumor volumes (MTVs) at 30%, 40%, 50%, 60%, and 70% of the primary tumor's maximum standardized uptake value (SUVmax). The geometric conformality or spatial overlap was assessed using the Dice similarity coefficient (DSC), which ranges from 0 to 1, indicating no overlap to complete overlap.

Results: The size of the tumor in the anteroposterior dimension of the GTV was found to be more on CT than MRI, with a mean difference of 0.29 cm (*P* value .015). Overall, PET-based MTV volumes were smaller than GTVs on CT and MR. Among various intensities on PET, MTV30 was the closest match with GTV-CT/MR. The mean difference for absolute tumor volumes (GTV-CT, GTV-MR, and MTV30) was not statistically significant; however, spatial overlap by DSC score was average, that is, <0.7. DSC was 0.65 $\pm$ 0.15 between GTV-CT and GTV-MR, 0.62 $\pm$ 0.15 between GTV-CT and MTV30, and 0.576 $\pm$ 0.16 between GTV-MR and MTV30 pairs, respectively. On qualitative analysis, overall tumor extension into adjacent muscles, parotid gland, retromolar trigone, and marrow infiltration of mandible was better appreciated on MRI.

Conclusions: Given the significant spatial variation, multimodality imaging can serve as an excellent complement for target volume delineation on CT scans during intensity modulated radiation therapy planning for LAOC by harnessing the improved soft tissue definition of MRI and the ability of PET to provide metabolic activity information.

Introduction

Accurate target volume delineation is essential for optimal treatment by intensity modulated radiation therapy techniques in radiation planning because of its ability to deliver radiation doses with high precision around the tumor while sparing surrounding healthy organs, leading to improved clinical outcomes. Although computed

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Research data are stored in an institutional repository and will be shared upon request to the corresponding author.

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tomography (CT) images provide morphologic information, they offer poor soft-tissue information and are associated with inconsistencies due to interobserver variation. To address these limitations, magnetic resonance imaging (MRI) and fluoro-deoxy-glucose-based positron emission tomography (FDG-PET) are being used more frequently for diagnostic staging, especially for advanced stages. MRI provides superior soft-tissue differentiation, and its image quality is less affected by artifacts from dental amalgam than CT. FDG-PET data provide information on metabolic tumor volume (MTV), also known as biologic target volume.[1-7] In this study, we focused on analyzing intermodality variation for gross tumor volume (GTV) delineation of the primary site in oropharyngeal squamous cell carcinoma.

Methods and Materials

This study received approval from the institute's ethical committee. We examined pretreatment MRI, pretreatment contrast-enhanced computed tomography (CECT), and FDG-PET RTP (radiation therapy treatment planning) image data sets of patients without metastasis with macroscopic, measurable, and histologically confirmed oropharyngeal squamous cell carcinoma. CECT used intravenous iodine-based contrast, whereas MRI used gadolinium-based contrast. Patients with histologic diagnoses other than oropharyngeal squamous cell carcinoma, previous irradiation, any previous history of surgical intervention, or any implants present in the head and neck region were excluded. We identified and selected retrospective data from RTP records based on inclusion criteria, and informed consent was exempted.

Image import procedure

The radiology and nuclear medicine department software, that is, picture archiving and communication system was used to search for the MR, CECT, and FDG-PET RTP image data sets of the patients. The images were then deidentified and assigned specific codes. The Eclipse treatment planning software (TPS, Version 16.0; Varian Medical Systems, Palo Alto, CA) was used to import the anonymized digital imaging and communications in medicine images.

Gross tumor volume (GTV) delineation (primary site)

New structure sets were created under CECT, MR, and PET series.

GTVs on CT and MRI

The GTVs were delineated by 2 radiation oncologists and 1 radiologist, who worked together to achieve a gold standard GTV on both CT and MRI. To ensure accuracy and avoid biases, they separated the delineation of each volume on different modalities for a particular patient by at least 2 weeks.

For the CECT component of PET-CT, with a slice thickness of 1.25 mm, the GTV-CT was delineated using uniform criteria for soft tissue (ie, contrast enhancement, left-to-right asymmetry, and fatty space infiltration) and cartilage/bone infiltration.[8] Meanwhile, the GTV on MRI (GTV-MR) was delineated using 1-mm slice thickness after blinding the PET-CT imaging. GTV was delineated on the axial T1 contrast sequence, in correlation with sagittal and coronal planes, and with the assistance of the other coregistered MRI sequences, ie, T2, noncontrast T1 and diffusion-weighted images blended to the T1 sequence. We contoured malignancy on T1/T2-weighted images based on unilateral changes in anatomy compared with the normal side, a mass effect, fat replacement, and hyperintensity relative to the surrounding soft tissue.[9]

MTV auto-delineation

An automatic segmentation, also known as the fixed threshold method, was used to obtain different intensity volumes in percentages of the maximum tumor standardized uptake value (SUVmax) for deriving the metabolic tumor volume using PET scans. As per the literature, we focused on 30% to 70% intensities.[4] The PET/CT images were processed using the Eclipse image registration software after ensuring the patient's weight and height were correctly entered to calculate the SUV normalized to the body surface area (SUV_{BSA}). A region of interest was drawn over the primary tumor area, and the point of maximum uptake was selected as the representative of SUVmax. We generated metabolic tumor volumes (MTVs) for 30%, 40%, 50%, 60%, and 70% of SUVmax.

Image registration and editing procedure

The CECT and PET sequences were registered automatically within the Wipro GE Health care advanced workstation 4.7 series without requiring any additional coregistration with each other on the Eclipse TPS. The imported MRI scans were coregistered with the CECT in the Eclipse treatment planning system using rigid image registration for further workflow. Rigid image registration was carried out between the 3-dimensional postcontrast T1-MRI sequence and the CECT. Initially, automatic rigid registration of the bony anatomy surrounding the oropharynx at the level of the lower clivus, C1 vertebra, and upper C2 vertebra was done, which was later refined manually by a trained radiation oncologist, as shown in Fig. 1. This was followed by a second trained radiation oncologist's review and approval of the registration.

After delineating GTVs on MR and PET-MTV generation, these structures were copied into the structure set under CT for editing, which involved checking for

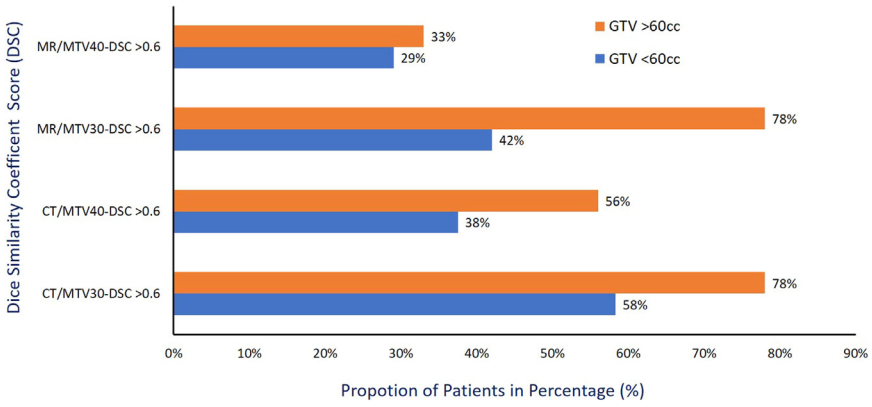

Figure 1 Axial, sagittal, and coronal coregistration and fusion of CT image sets with T1C-3D MR set using bony landmarks (dens of C2 protrusion at level of C1 vertebra) in LAOC. *Abbreviations:* CT = computed tomography; DSC = Dice similarity coefficient; LAOC = locally advanced oropharyngeal carcinoma; T1C-3D MR = T1-contrast 3-dimensional magnetic resonance imaging; MTV = metabolic tumor volume. (A color version of this figure is available at 10.1016/j.adro.2024.101453.)

artifacts or air cavities. Any necessary corrections were made to PET images for normal physiological uptake as per the judgment of the nuclear medicine physician.

Data measurements

Quantitative measurement of GTV/MTV

Two different structures, GTV-CT and GTV-MR, were compared individually. Both were considered the gold standard to compare with various MTVs obtained through PET scans to determine the optimal intensity/threshold. Quantitative calculations were performed, which included the absolute volumes of each modality and the intermodality conjunction/overlap volumes using boolean operations on the TPS. The absolute volume difference and intermodality overlap volumes (intersection) were measured in the following pairs: GTV-CT versus GTV-MR, GTV-CT versus PET-MTVs (30%, 40%, 50%, 60%, 70%), and GTV-MR versus PET-MTVs (30%, 40%, 50%, 60%, 70%). Intermodality variability in overlap volumes was checked using the sensitivity and inclusion indexes. The sensitivity index (SI) measures how much of the second-named gross tumor volume (GTV) is contained within the first-named GTV. For CT-PET, the SI is calculated as the intersection of the GTV-CT and PET-MTV divided by the PET-MTV alone (GTV-CT ∩ PET-MTV / PET-MTV). The inclusion index (II) measures how much of the first-named GTV is contained within the second. For CT-PET, the II is calculated as the intersection of the GTV-CT and PET-MTV divided by the GTV-CT alone (GTV-CT ∩ PET-MTV / GTV-CT).

Measurement of conformality parameters

Geometric conformality or spatial similarity was assessed using the Dice similarity coefficient (DSC) to measure the extent of spatial overlap between 2 volumes. A DSC score of 0 indicates no overlap, whereas a score of 1 indicates complete overlap, indicating agreement in both volume and spatial location.[10,11]

For instance, the DSC for GTV-CT and GTV-MR can be calculated as DSC = 2 (A ∩ B) / A + B, where A is the volume from GTV-CT, B is the volume from GTV-MR, and (A ∩ B) is the intersection of volumes A and B.

We compared the spatial characteristics of the following pairs: GTV-CT versus GTV-MR, GTV-CT versus PET-MTVs (30%, 40%, 50%, 60%, 70%), and GTV-MR versus PET-MTVs (30%, 40%, 50%, 60%, 70%). We also noted the center of mass shift in the X, Y, and Z directions for the following pairs: GTV-CT versus GTV-MR and GTV-CT versus PET-MTV.

Statistical analysis

Categorical variables were summarized as frequencies/proportions with percentages. Mean and standard deviation were used to summarize continuous variables. The paired *t* test or Wilcoxon signed-rank test was used to compare differences between intermodality. Karl Pearson correlation or Spearman rank correlation was used to analyze the correlation between intermodality volumes. The Kolmogorov-Smirnov test was used to check the normality of the data. A 2-tailed *P* value of less than .05 was considered statistically significant. The Statistical Package for Social Sciences software, version 19 (IBM Corp., Armonk, NY) was used for statistical analysis.

Results

We conducted an analytical study of CT, MRI, and FDG-PET images for primary oropharyngeal squamous cell carcinoma to measure variation in gross tumor volume. Table 1 shows the baseline characteristics of 33 cases.

Table 1 Sex-wise and subsite-wise distribution of patients with locally advanced oropharyngeal carcinoma

Parameter	Frequency (n = 33)	Percentage
Sex		
Male	28/33	85%
Female	5/33	15%
Tumor subsite (epicenter)		
Base of tongue	11/33	33%
Soft palate	5/33	15%
Tonsil	17/33	52%
T-stage		
T2	8/33	24%
T3	8/33	24%
T4	17/33	52%

Tumor dimensions on CT/MRI

We measured the dimensions of GTVs (gross tumor volumes) on CT and MR images. The mean values for the anteroposterior dimension were 4.45 ± 1.12 cm and 4.16 ± 1.21 cm on CT and MRI, respectively. The mean values for the mediolateral dimension were 4.5 ± 1.34 cm and 4.54 ± 1.40 cm on CT and MRI, respectively. The mean values for the craniocaudal dimension were 4.88 ± 1.65 cm and 5.03 ± 1.67 cm on CT and MRI, respectively. There was no significant difference in mediolateral and craniocaudal dimensions between CT and MRI. However, there was a significant difference in the anteroposterior dimension, with a mean difference of 0.29 cm (95% confidence interval [CI], 0.06-0.51) and a *P* value of .015.

Tumor volumes on CT/MRI/PET

We calculated the average values for gross tumor volume on CT and MRI to be 42.02 ± 28.75 cc and 43.55 ± 31.69 cc, respectively. The mean value for MTV30 was 40.2 ± 29.3 cc, for MTV40 was 25.3 ± 21.9 cc, for MTV50 was 16.3 ± 16 cc, MTV60 was 10.4 ± 11.1 cc, and MTV70 was 5.2 ± 6.1 cc, respectively on PET. These findings suggest that the volumes obtained by automatic segmentation, especially MTV40 onwards, were relatively smaller than those obtained on CT and MRI.

Multimodality absolute volume differences

There was no significant mean difference between GTV-CT and GTV-MR (−1.53 cc; 95% CI, −5.1 to 2.0; *P* value .390). The Pearson correlation test revealed a significant correlation between GTV-CT and GTV-MR with a *P* value <.01. The mean difference between GTV-CT and MTV30 (1.82 cc; 95% CI, −6.172 to 9.73; *P* value .652) and GTV-MR versus MTVs 30% (3.35 cc; 95% CI, −4.51 to 11.13; *P* value .395) was not statistically significant. There was a statistically significant difference between GTVs on CT/MR images versus MTVs 40% to MTV 70% intensities on PET images ($P < .001$).

Conjunction and intersection volumes

The mean value for conjunction volume between GTV-CT and GTV-MR was 55.1 ± 37 cc, whereas the intersection/overlap volume was observed to be 30.6 ± 23.68 cc. The mean value for conjunction volume between GTV-CT and MTV-30 was 55.9 ± 34.8 cc; between GTV-MR and MTV30, it was 58.4 ± 38 cc. The mean value for intersection/overlap volume between GTV-CT and MTV-30 was 26.5 ± 20.2 cc; between GTV-MR and MTV30, it was 25.4 ± 20.3 cc.

Indices (SI and II) and DSC

The results for SI and II and the DSC are shown in Table 2. The highest sensitivity index was observed for the GTV-CT/MTV30 pair. The highest inclusion index was observed for the GTV-CT/MR pair. DSC score was highest between GTV-CT and GTV-MR. The DSC score of MTV 30 was 0.62 and 0.58 with GTV-CT and GTV-MR, respectively. However, the DSC value was less than 0.5 for MTV 50% to 70% intensities on PET for both CT and MR GTVs. Among the subsites, the base of the tongue had the best match, with mean DSC scores of CT/MRI with MTV-30/40 being approximately 70%. In contrast, the soft palate subsite had the least match, with only 40% match with CT-MTV30/40 and 20% match with MR-MTV30/40. The tonsil subsite had a CT-MTV30 match of 41%, and MR-MTV40 had a DSC score of 53%.

Center of mass shift (COM)

Regarding the GTV-CT coordinates, the mean shifts of the COM were highest and statistically significant in the negative X and Z directions, measuring at 0.34 ± 0.36 and 0.41 ± 0.29, respectively, compared with other directional changes for the GTV-CT and GTV-MR pair. Similarly, the mean shifts for the GTV-CT and MTV-30 pair were highest and statistically significant in the negative X and Z directions, measuring at 0.61 ± 0.49 and 0.53 ± 0.60, respectively, compared with other directional changes.

Table 2 Indices and DSC scores between GTV-CT, GTV-MR, and MTV pairs

Parameter	Sensitivity index, mean	Inclusion index, mean	Dice similarity coefficient (DSC), mean
GTV-CT/MR	0.66 ± 0.16	0.67 ± 0.17	0.65 ± 0.15
GTV-CT/MTV30	0.69 ± 0.23	0.63 ± 0.15	0.62 ± 0.15
GTV-CT/MTV40	0.82 ± 0.17	0.46 ± 0.16	0.57 ± 0.14
GTV-CT/MTV50	0.89 ± 0.12	0.31 ± 0.15	0.44 ± 0.15
GTV-CT/MTV60	0.91 ± 0.11	0.21 ± 0.13	0.32 ± 0.16
GTV-CT/MTV70	0.92 ± 0.11	0.10 ± 0.09	0.17 ± 0.13
GTV-MR/MTV30	0.65 ± 0.24	0.58 ± 0.15	0.58 ± 0.16
GTV-MR/MTV40	0.77 ± 0.21	0.42 ± 0.16	0.52 ± 0.16
GTV-MR/MTV50	0.82 ± 0.21	0.29 ± 0.15	0.40 ± 0.17
GTV-MR/MTV60	0.85 ± 0.21	0.19 ± 0.14	0.29 ± 0.16
GTV-MR/MTV70	0.89 ± 0.21	0.10 ± 0.10	0.17 ± 0.14

Abbreviations: DSC = Dice similarity coefficient GTV-CT = gross tumor volume on computed tomography scan; GTV-MR = gross tumor volume on magnetic resonance imaging; II = inclusion index; MTV-30-70 = metabolic tumor volume derived at 30%-70% intensities of maximum standardized uptake value at primary tumor site on positron emission tomography; SI = sensitivity index.
DSC for GTV-CT and GTV-MR is derived as DSC = 2 (A ∩ B) / A + B, where A = volume from GTV-CT, B = volume from GTV-MR, (A ∩ B) = intersect of volumes A and B.
SI measures how much of the second-named GTV is contained within the first-named GTV. For CT-PET, the SI is calculated as the intersection of the GTV-CT and PET-MTV divided by the PET-MTV alone. (GTV-CT ∩ PET-MTV / PET-MTV).
II measures how much of the first-named GTV is contained within the second, ie, for CT-PET, II is calculated as the intersection of the GTV-CT and PET-MTV divided by the GTV-CT alone. (GTV-CT ∩ PET-MTV / GTV-CT).

Tumor volume and DSC score relationship

We conducted an analysis of the tumor volume, and determined the proportion of patients (%) with a DSC score greater than 0.6 for GTV-CT/MTV30, GTV-CT/MTV40, GTV-MR/MTV30, and GTV-MR/MTV40 pairs (as shown in Fig. 2: bar diagram). We observed that if GTV was more than 60 cc (which is approximately tumor stage T3) on CT and MRI, then MTV30-DSC >0.6 corresponded to 78% of cases. However, when GTV was less than 60 cc on CT and MRI, then MTV30-DSC >0.6 corresponded to only 58% for CT and 42% for MR, respectively (as shown in Fig. 2).

Discussion

Tumor extent for oropharyngeal cancer can be determined by thorough clinical examination and diagnostic imaging such as CT, MRI, and FDG-PET. When assessing the soft-tissue or bone extension of head and neck malignancies, MRI with unenhanced T1, contrast-enhanced T1, and T2-weighted sequences with or without fat suppression has been proven to be more accurate than CT.[1] PET-based functional imaging provides information on metabolically active tumor volume, but there are various interpretation and segmentation methods to detect MTVs, including visual interpretation, fixed SUV value, fixed threshold value of maximum signal intensity, or adaptive threshold based on a signal-to-background ratio.[7] There is still uncertainty about the most effective method or intensity for accurately identifying tumors in the head and neck.[12-14] In addition to these technical issues, interobserver and intraobserver variations can lead to changes in tumor delineation.[15,16]

In our study, a large proportion of tumors were found to be in the locally advanced stage; 76% were categorized as T3 or T4. MRI-based contrast enhancement was more effective in detecting these tumors than CT scans. The maximum difference was observed in the anteroposterior dimension and was statistically significant with a mean difference of 0.29 cm (95% CI, 0.06-0.51, *P* value of .015). We found that anteriorly extension to the tongue, anterolaterally to retromolar trigone, laterally to medial pterygoid (Fig. 3), direct parotid extension, and posteriorly prevertebral muscle extension were seen with clarity on MRIs compared with CT scan. It was challenging to differentiate the involvement of the medial retropharyngeal lymph node from a primary tumor on a CT scan compared with an MRI-T1 contrast image at the same level. In addition, MRI can identify easily necrotic regions inside large tumors/nodes compared with CT (Fig. 4). However, in their study, Becker et al[17] concluded that MRI may overestimate cartilage infiltration in laryngopharyngeal cancers due to its inability to differentiate between inflammatory and neoplastic changes.

PET-based MTV30 showed FDG uptake in left and right retropharyngeal lymph nodes in addition to the primary tumor (Fig. 4); however, it was feasible to differentiate retropharyngeal nodes separately from the tumor.

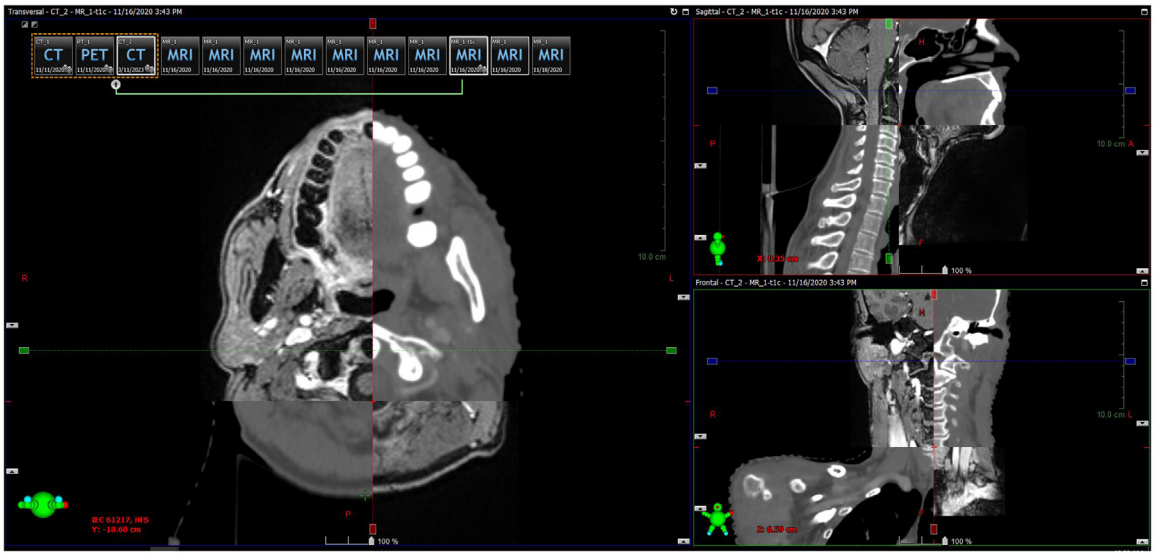

Figure 2 Tumor volume wise proportion of patients (%) greater than DSC score >0.6 for MR/MTV30, MR/MTV40, CT/MTV30, and CT/MTV40 pairs. For large tumors with gross tumor volume >60 cc MTV30% PET-based intensity derived from SUV_{max} by automatic segmentation method closely matches in terms of spatial conformity to gross tumor volume on CT and MRI. *Abbreviations:* cc = cubic centimeter; CT = computed tomography; CT/MTV-30/40-DSC = Dice similarity coefficient between gross tumor volume on computed tomography and metabolic tumor volume derived from 30%/40% intensity of maximum standardized uptake value (SUV_{max}) on fluoro-deoxy glucose positron emission tomography; GTV = gross tumor volume; MR/MTV-30/40-DSC = Dice similarity coefficient between gross tumor volume on magnetic resonance imaging and metabolic tumor volume derived from 30%/40% intensity of maximum standardized uptake value on fluoro-deoxy glucose positron emission tomography; MRI = magnetic resonance imaging; PET = positron emission tomography. (A color version of this figure is available at 10.1016/j.adro.2024.101453.)

We observed no significant difference in the absolute volumes (GTV-CT and GTV-MR) between the 2 modalities. However, the conjunction volumes between the 2 modalities increased by 31%, whereas the intersection volume was only 73%. Although MRI is best for soft-tissue resolution and CT imaging is good at providing information on bone or cartilage invasion, other technical factors could contribute to the observed spatial differences between the 2 modalities. These include: (1) Overestimation or underestimation of tumor volume on CT may occur due to poor contrast uptake or subjective interpretation errors. (2) The study used bony landmark-based coregistration between CT and MRI instead of soft-tissue matching for uniformity. (3) CT and MRI-based setup reproducibility issues or movement of soft tissues due to deglutition during the acquisition of images.

Quantitatively, we found mean PET-based MTV30 volume corresponded similarly to GTV-CT and GTV-MR, and MTV40-MTV70 volumes were significantly lower compared with GTV-CT and MR.

In a study by Samołyk-Kogaczewska et al,[16] the role of PET imaging in GTV delineation was evaluated using visual interpretation and a quantitative automatic segmentation method based on 20% to 50% of standardized uptake values (SUVmax). The researchers found that the closest match for primary gross tumor delineation was 30% of SUVmax, whereas 30% to 40% of SUVmax was found to be the best for nodal GTV determination.

We also observed that conjunction volumes of GTV-CT and MTV30 increased by 33% (in reference to GT-CTV), and the intersection was only 63%. Conjunction volumes of GTV-MR and MTV30 increased by 34.2%, and the intersection was only 58.7%.

In this study, overall, GTV-MR contained within GTV-CT was 66%, and GTV-CT contained within GTV-MR was 67%. GTV-CT and GTV-MR had the best inclusion index score with MTV30 among various intensities on PET.

MTVs from 40% to 70% intensities of PET were almost confined within the GTV-CT ranging from 82% to 92%, and within GTV-MR volume with very high SI values ranging from 77% to 89%. The Spearman correlation coefficient for MTV intensities with GTV-CT and GTV-MR was also more than 0.7, with a P value <. 001.

The average inclusion index values for MTVs with 40% to 70% intensities were low (<0.5) with GTV-CT and GTV-MR. This is because the average metabolic volumes were lower than the mean GTV-CT and mean GTV-MR values.

Paulino et al[13] also found that PET-MTV50, which is derived from automatic segmentation, was smaller than GT-CTV in 75% of a heterogeneous group of 40 patients with head and neck squamous cell carcinoma.

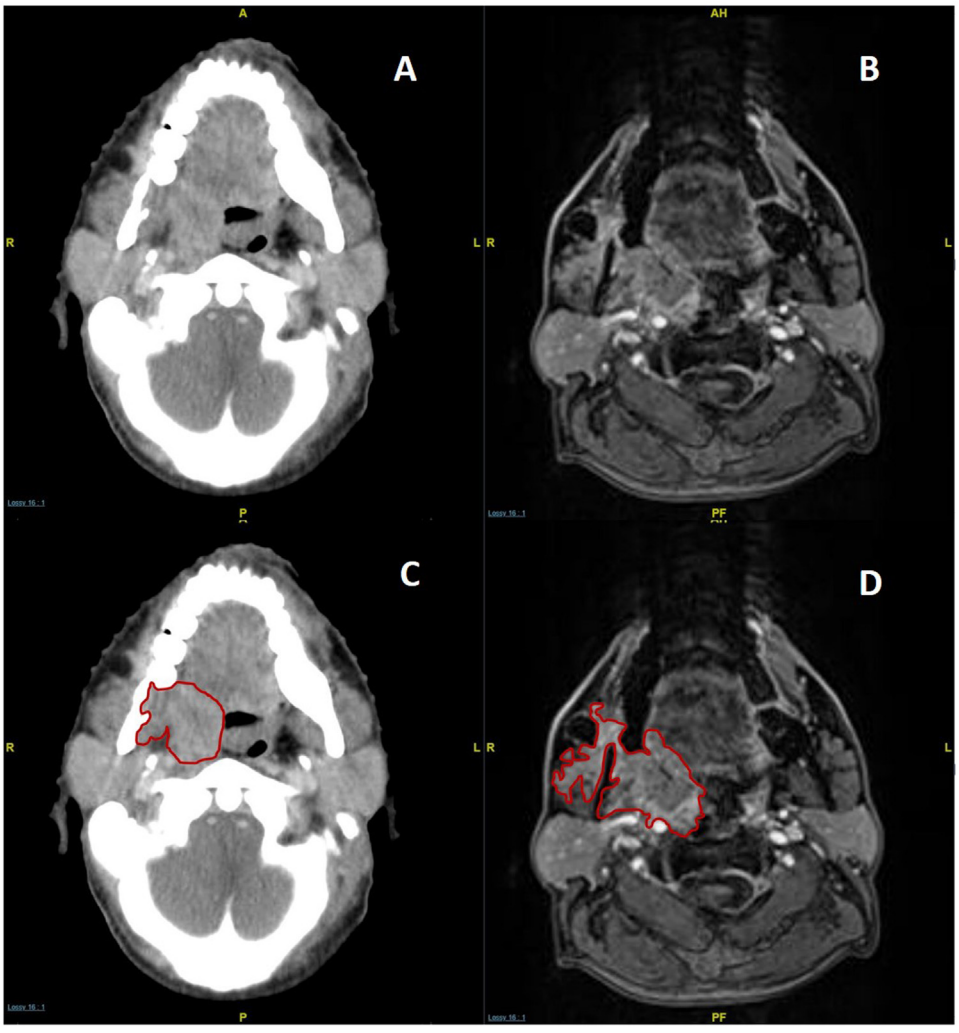

Figure 3 Lateral masticator space extension (involvement of masseter muscle) of tumor seen with better clarity on MRI compared with CT image. Axial section of CT scan (left side) post-iodine contrast (A: GTV not contoured and C: GTV contoured in maroon) showing right side tonsil tumor extending to right retromolar trigone, medial pterygoid with erosion of inner mandibular cortex. At the same level, axial section of T1- MR scan (right side) postgadolinium contrast (B: GTV not contoured and D: GTV contoured in maroon) showing right side tonsil tumor extending to right masseter muscle beyond right retromolar trigone, medial pterygoid, and with erosion of inner mandibular cortex. *Abbreviations:* CT = computed tomography; GTV = gross tumor volume; MRI = magnetic resonance imaging. (A color version of this figure is available at 10.1016/j.adro.2024.101453.)

On spatial conformity analysis by DSC, we found that the mean value for DSC between GTV-CT/GTV-MR was 0.65 ± 0.15. The mean DSC value between GTV-CT/MTV30 and GTV-CT/MTV40 was 0.62 ± 0.15 and 0.57 ± 0.14, respectively. The mean DSC value between GTV-MR/MTV30 and GTV-MR/MTV40 was 0.576 ± 0.16 and 0.523 ± 0.16, respectively. In CT and MR GTVs, the DSC value was less than 0.5 for MTV 50% to 70% intensities on PET. The base of tongue subsite showed the best match with mean DSC scores of CT/MR with MTV-30/40 (approximately 70%).

An analysis was conducted on the COM shift, which is another measure of directional conformity and positional analysis, to assess directional shifts in relation to GTV-CT coordinates. The highest COM mean shifts were observed in the X and Z negative directions for GTV-CT/MR and GTV-CT/MTV-30 pairs, compared with other directional changes. If CT-based planning is the only option, expanding margins asymmetrically on the lateral and caudal sides may be necessary during CTV delineation or PTV margin setup to prevent any geographic miss. However, multimodality imaging should be used for gross tumor volume delineation to ensure greater accuracy.

Bird et al[18] observed significant differences in positional changes of oropharyngeal squamous cell carcinoma from CT, MR, CT-MR, and PET-based image data. On average, 54% to 58% of the CT and MR-based GTVs were included within PET GTVs.

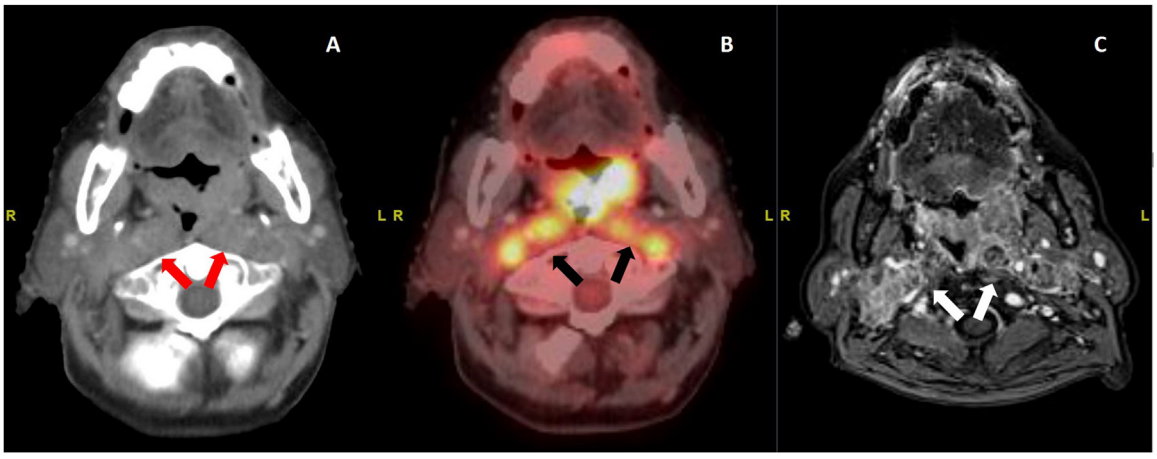

Figure 4 Differential assessment of RPN from primary tumor on axial sections of CECT (left, red arrows), PET-MTV30 (mid, black arrows), and MR (right, white arrows). Regional nodal metastasis to medial retropharyngeal lymph node was better differentiated from primary tumor on T1-contrast MRI than CECT. Although PET-MTV30 is showing FDG uptake in left and right RPNs in addition to primary tumor, it is feasible to identify RPN separately from the tumor.
Abbreviations: CECT = contrast-enhanced computed tomography; MRI = magnetic resonance imaging; PET-MTV30 = metabolic tumor volume 30% intensity of maximum standardized uptake value on positron emission tomography; RPN = retropharyngeal node. (A color version of this figure is available at 10.1016/j.adro.2024.101453.)

Based on our observations, we found that PET-MTV with 30% intensity of SUVmax had a DSC score greater than 0.6 with GTV-CT and GTV-MR separately in cases where GTV was larger than 60 cc, compared with smaller tumor volumes.

Limitations

We conducted this study with a limited number of patients, so validating the results on a large sample size is necessary. We used a custom-made immobilization device to match the radiation therapy setup while acquiring MRI scans to ensure accurate results. A flat couch-based MRI setup, similar to a CT simulator, would be better to decrease directional shifts.

In this study, we used an automatic segmentation method to derive MTVs on PET. This method has some limitations, such as the inability to define the tumor edge due to resolution blur, not accounting for the heterogeneity of SUV within tumors, and the lack of pathologic validation. In some cases, we found that the contrast uptake of the tumor was not of good quality compared with normal tissues on CT. This could be due to inherent tumor biology or a technical issue, such as poor timing of contrast or inadequate contrast.

To minimize organ motion errors during the acquisition of MRI, patient counseling can be considered to restrict swallowing motion. However, it can be challenging for all patients to follow this approach as it involves multisequence imaging. Multimodality imaging may underestimate mucosal extension; therefore, it is better to incorporate local physical or endoscopy findings in tumor volume delineation where possible. In advanced cases, the presence of trismus limits local physical examination availability.

Conclusions

CT imaging is essential for radiation treatment planning, as dosimetric calculations rely on Hounsfield units. Considering the limitations of CT imaging and subjective interpretation-based uncertainties, inputs from MRI and PET intensity-based MTV can complement CT scans to improve the accuracy of GTV delineation. Although we did not observe a statistically significant difference between the absolute volumes of GTV-CT and GTV-MR, the calculated DSC suggests that the spatial overlap between these volumes was only average (<0.7). This finding indicates a scope for improvement in achieving a greater level of overlap between the 2 volumes. MRI is superior to CT imaging because of its better contrast and multiplanar imaging capabilities. MRI is especially useful in identifying soft-tissue extension to or from the anterior tongue, parotid or submandibular glands, masticator/prevertebral muscle infiltration, and bone marrow infiltration. Among PET intensities, MTV30 was the closest match for GTV-CT and GTV-MR in primary oropharyngeal carcinoma. Our study highlights the importance of multimodality imaging for gross tumor volume delineation. This approach can help prevent geographic misses in intensity modulated radiation therapy-based radiation therapy planning.

Disclosures

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Supplementary materials

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